DOE

ENERGY STORAGE

SYSTEMS PROGRAM

Quarterly Progress Report
for
January — March 2003

(Second Quarter / Fiscal Year 2003)

Energy Storage Systems Department

(ESS)

Sandia National Laboratories — Albuquerque, NM

Table of Contents

STRATEGIC ANALYSIS

System Integration

Alaska Battery/Diesel System Model

Alaska offers significant opportunities for the introduction of energy storage into distributed resource electricity supply systems. One such opportunity is in progress by the Alaskan Energy Authority (AEA). Based on feedback and cooperative review of activities between Sandia National Laboratories (SNL) and the AEA, the two entities have developed a battery-diesel system model designed to reduce fuel consumption, increase performance, and improve the rigor and reliability of power in remote Alaskan villages.

Provided for in a contract with Sentech, the model concentrates on the feasibility of coupling battery energy storage systems with existing diesel generators (including photovoltaic hybrids in some cases) to evaluate different scenarios for using battery storage with small, stand-alone diesel gensets.

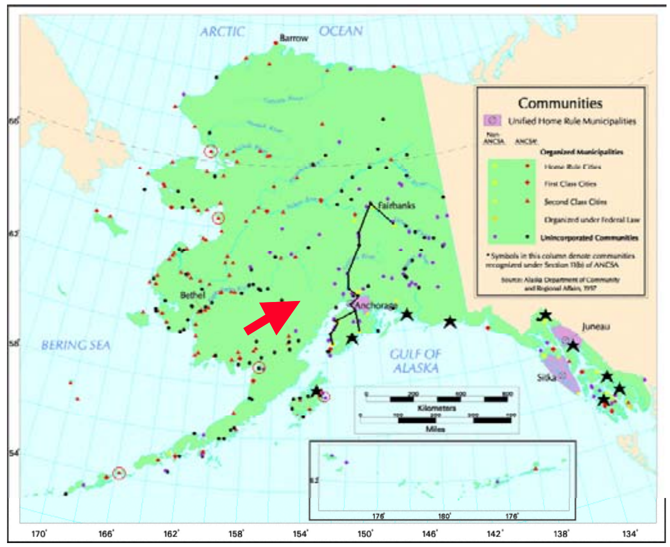


Fig. 1: Site of Test-Bed Solar/Diesel/Battery System in Remote Area of Alaska

The modeling and analyses have revealed that benefits can be gained from a storage-diesel system.

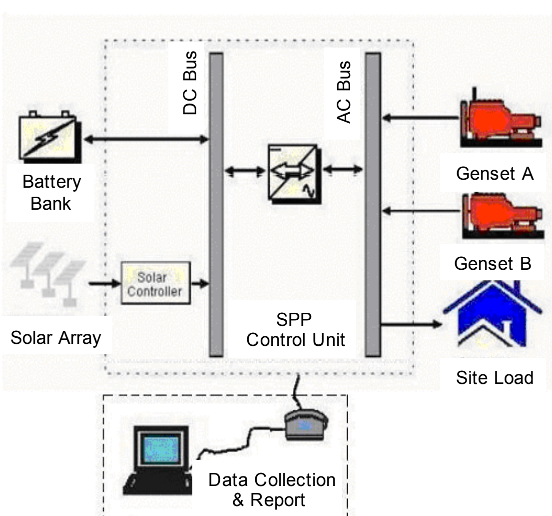


Fig. 2: Diagram of Model Solar/Diesel/Battery System

During FY01 the model was converted to modular code architecture (Fig. 2) and SNL provided technical and financial support to AEA for completion and installation of a photovoltaic (PV) system to an existing battery storage/diesel genset system in Lime Village, Alaska (See below: ***<u>Alaska Battery/Diesel/PV-Hybrid Test Bed System (Lime Village)</u>)***. Based on analysis, SNL reasoned that data from this project would be beneficial for validating the model.

SNL and the AEA also began a collaborative effort to develop the necessary elements for a test bed for data acquisition at Lime Village (See below: ***<u>Lime Village Test Bed Data Acquisition and Reporting</u>***).

A new contract was placed with Sentech during the second quarter of FY02, under which:

- PV analysis capability was incorporated into the model and the resulting performance validated;
- Upgrades and enhancements to the model were added;
- Preparation for detailed feasibility studies in FY03 were instituted, which would lead to the design, fabrication, installation, and testing during FY04 of a prototype system;
- Code development was completed and incorporated, which allowed Version 1 of the model to perform an analysis and determine an optimized system (Version 2), given the conditions; and
- The optimization routine and a PV system were incorporated into Version 2 during the fourth quarter of FY02.

The improvements made to the model up through the end of the first quarter of FY03 should substantially increase both its utility and its accuracy.

Once all of the improvements have been thoroughly tested and validated, the model will be ready for application in identifying promising sites for hybrid system installations. It will also be available for interested parties to perform their own analyses and confirm the benefits of installing hybrid systems in other villages, as well as aid in sizing and configuring those systems.

Second Quarter Status

This year, the second quarter of the project consisted primarily of contract activities between Sandia and the AEA.

Under the new contract, we will continue to complete the testing and validation of the model, which will include technical performance of the model and user testing for feedback on interface and ease of use.

Our goal is to get the model into the hands of the Alaskan agencies and establish a user base. We will then support the AEA by performing technical and economical analyses for system improvement for one to two village systems identified by the AEA. In addition, we will fully support the annual AEA Energy Conference through participation and technical support of seminars.

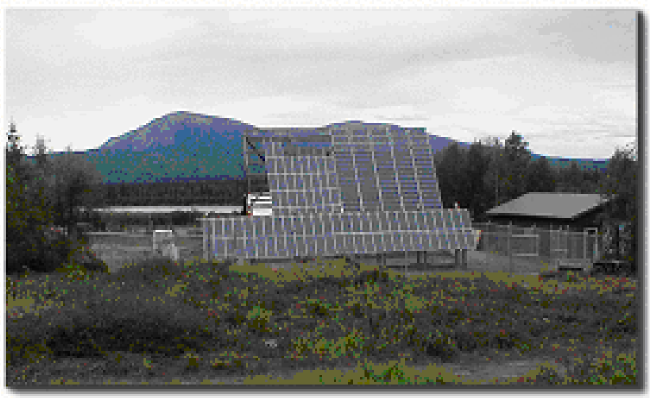
↑ Table of Contents

Alaska Battery/Diesel/PV-Hybrid Test Bed System (Lime Village)

In concert with the results from a collaborative modeling effort (See**: *Alaska Battery-Diesel Model System***, above), Sandia National Laboratories (SNL) and the AEA have agreed to install battery storage systems with small, stand-alone, distributed diesel generators (gensets) and photovoltaic (PV) arrays in a remote Alaskan community named Lime Village. McGrath Light and Power, on behalf of the Lime Village Traditional Council, will perform the actual construction, operations, and management of the system.

Managed and funded by AEA, the Lime Village project is designed to both provide the community of Lime Village with reliable and affordable electricity and to validate the Battery/Diesel/PV model mentioned above. Lime Village is a reconfiguration of the established prototype diesel-hybrid system, coupled with an expanded PV array and a new, smaller diesel generator set, that will provide the opportunity for collecting real time data on Alaskan Village hybrid systems for further modeling development and optimization of technical and market analysis. The AEA believes the battery/diesel/PV approach will provide the community with optimal fuel savings and regards the potential success of this test-bed project as a model for expanding opportunities to other Alaskan villages with similar needs.

At one point, technological and funding limitations had prevented the purchase of a suitable inverter and a scheme for system integration. With the assistance of Sandia National Laboratories, however, all major system components, except the inverter, have been purchased and installed.



Lime Village Test-Bed: Typical Expanded Solar Array

During FY02, a contract with McGrath Power and Light was put in place for the installation of sensors and meters and maintenance of Lime Village systems in support of test bed availability. Installation of some of the key meters and sensors was also completed.

Lime Village Test-Bed: Typical Diesel Generator

A separate contract established data acquisition and reporting (See below: ***Lime Village Test Bed Data Acquisition and Reporting***). A Starband Communications System provides the capability to transmit the test bed data to the Internet. Lime Villagers have been trained in the operation and maintenance of the system.

During FY03, fuel flow meters and a DC input/ output current meter for each PV array are being installed, which will complete the majority of requirements to validate the Battery/Diesel/PV model.

The battery system in Lime Village began to fail during the first quarter of this year. Therefore, negotiations between AEA and McGrath to provide a replacement were put into place, with SNL offering technical support for specifications for the replacement system.

Second Quarter Status

This quarter consisted primarily of contract activities between Sandia and the AEA.

Advancement of the project during FY03 involves furthering test bed development for data validation, to include identification, purchase, and installation of the necessary hardware. In addition, the battery system will be upgraded and data retrieval and reporting capabilities (via the web site) will continue to be maintained and developed for improvements.

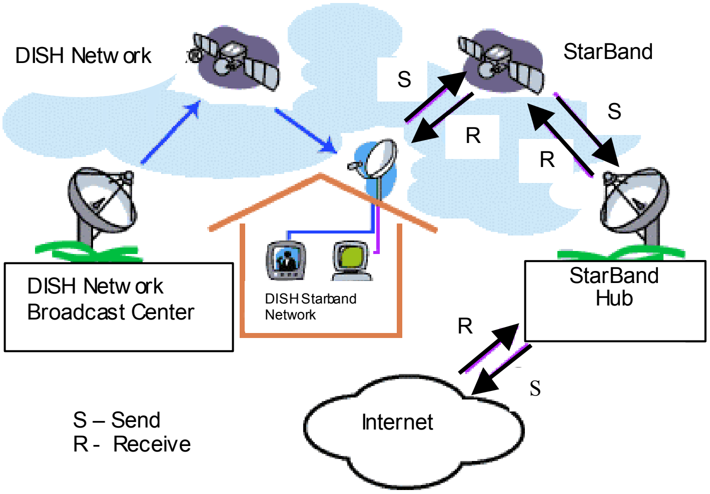
Lime Village Data Collection Site

Interior of Lime Village Data Collection Site:
Data Console (left); Inverter (center); Storage Batteries (right)

↑ Table of Contents

Alaska Village Test Bed Data Acquisition and Reporting

This contract to design and install a communication interface (data transmission) from Lime Village, Alaska to the AEA and SNL via UAF was awarded during the second quarter of FY02. A Starband Communications system for satellite retrieval of data was installed and successfully tested.



Data Transmission Using Starband Communications System

In collaboration with AEA, SNL managed the University of Alaska at Fairbanks in completing the design and installation of a reliable data-retrieval interface that satisfies SNL requirements for the test bed.

UAF designed the communication scheme and all necessary software, along with identifying all required COTS, plus the hardware configuration that would successfully transmit data to AEA and SNL in the required formats.

Data acquisition schemes were designed and developed during the fourth quarter of FY02. In addition, reporting requirements were established and actual reports begun.

A UAF student was selected for work on this project. During the summer months, the student reports directly to the AEA. SNL has provided the data acquisition requirements.

Second Quarter Status

Development activities for this data acquisition and reporting project are now complete and stewardship of data acquisition and maintenance will be managed and reported, henceforth, under the Lime Village test bed project (See above: ***Alaska Battery/Diesel/PV-Hybrid Test Bed System at Lime Village***).

↑ Table of Contents

ABESS (Advanced Battery Energy Storage System)/PV System

The ESS Program (ESS) has a long-term agreement to develop zinc bromine batteries with ZBB. One project provides field-testing for two advanced battery energy storage systems (200kW/400kWh and 50kW/100kWh) based on zinc bromine battery technology in load-leveling/peak shaving applications.

ZBB built a 200kW/400kWh system in cost-shared contracts with the ESS Program. Two real-time tests of the system were successfully conducted at two Detroit Edison sites. Detroit Edison and ZBB then decommissioned the system and returned it to ZBB's factory for re-furbishing.

ESS began a second project with ZBB that calls for a 50kW/100kWh system. Called the "Greenpoint PV-Battery System," PowerLight contracted with The Greenpoint Manufacturing and Design Center (GMDC), a non-profit arts and industry organization that purchases and rehabilitates historic buildings in the Greenpoint area of Brooklyn, to install a 50 kWac PV system at PowerLight's Humboldt Street facility. GMDC holds the Con Edison accounts for this facility and uses sub-meters to bill each tenant separately. The coincident daily peak load of the building on business days is roughly 80 kWac.

PowerLight has decided to use the Humboldt facility as the site for one of ZBB's three NYSERDA Hi-Value battery systems. This zinc-bromine peak shaving battery can be used to absorb weekend PV production and dispatch it throughout the week. The 50 kWac PV system will be integrated with the standard ZBB 50 kW/100 kWh battery. On weekdays, the battery can be discharged to help reduce the customer load. The PV-Battery system can, therefore, be described as 75 or 80 kW peak.

Second Quarter Status

Detroit Edison

Testing of the 400kWh battery at the Detroit Edison site has been temporarily halted while the batteries are again being refurbished. Four batteries on the upper level of the shipping container were removed and returned to ZBB for refurbishing during the first quarter. It was decided to return the four remaining modules along with the shipping container and the power conversion equipment (PCS) to ZBB's factory for reconditioning and further testing in conjunction with a local (Wisconsin) utility

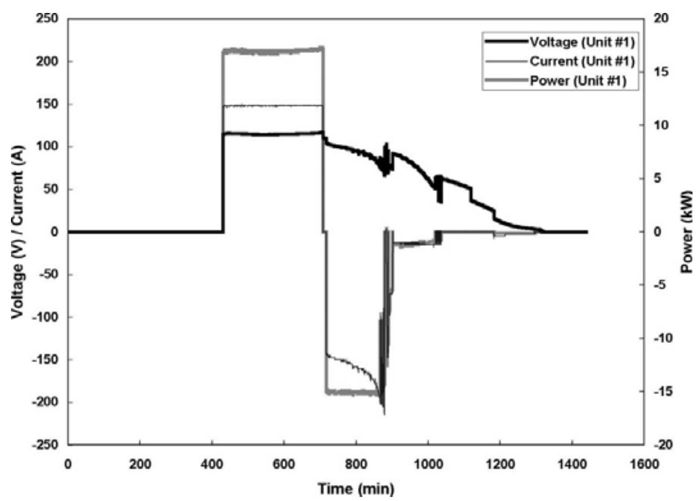
Greenpoint

Shutdown and fault conditions were tested for each module of the 100kWh system by artificially introducing the condition and verifying the system response. During a fault condition, the DC contactor is opened, while the pumps and control system continue to operate. During a shutdown condition, the contactor is opened and the pumps are stopped. The system responded appropriately to all artificially induced fault and shutdown conditions.

AC power capabilities of the 100kWh system were tested by commanding the system to perform automatic charges/discharges at specific power levels (the system begins the test completely discharged). The power levels were measured with a hand-held meter and the measured results compared to the results reported by the system software. All results were within the expected parameters.

A series of tests was performed to observe the automatic startup of the 100kWh system following a power outage. The results of the tests were positive. The battery system automatically completed the startup sequence and came on line in the idle mode, regardless of the mode of operation prior to the outage or the time duration of the power outage. For a very short, almost instantaneous outage, the system shut down and the battery resumed where it was before the outage.

Constant power discharge testing was performed on the 100kWh system. An example of a constant power (25 kW AC / 30 kW DC) discharge is shown in the graph below. The battery operated properly, although the performance was slightly less than expected. The battery only provided about 45 kWh DC, (50 kWh were expected). Testing is continuing to improve the performance of the battery under constant power discharge tests. When the output for the system reaches an acceptable level, the remaining factory testing and witness testing will be completed and the system will be sent to the Humboldt site



Constant 25 kW (AC) / 30 kW (DC) Power Discharge for a Battery Module

↑ Table of Contents

Alternative RGS System Designs to Improve Battery Performance

The purpose of this alternative configurations project is to develop and validate integrated devices that will improve system reliability and component performance, and reduce the life-cycle-costs of continuous power systems, such as renewable generation systems (RGS). Currently, the primary objective of this project is to provide a means to optimally manage the charging and discharging of the energy storage batteries in RGS solar-hybrid systems.

Previous work under this contract has included conceptualization of alternative configurations for batteries in hybrid power systems that might thereby reduce life-cycle-costs, and development and testing of breadboard units that allowed verification of the advantages of the approach. Work has been underway on this project since the fourth quarter of FY98. Non-optimal performance of current solar-hybrid systems was analyzed and several alternative configurations were conceptualized and modeled to verify that the design concepts would lead to improved system performance.

By providing a means to optimally manage charge and discharge, we mean to develop alternative configurations for solar-hybrid systems so that each of the components will be used in such a way as to minimize the total life cycle cost. Secondary objectives for the work include improving the communications among battery suppliers, power converter developers, and customers; and evaluating the utility of the methods developed in the work to other battery applications, such as provision for standby power.

During the latter part of FY99 and through FY00, three prototypes of one of the alternative configurations (called ACONF) were built and tested to validate the modeling work. In FY01 and FY02, three copies of the prototypes were installed and are currently being tested at the Arizona Public Service Solar Test and Research (STAR) Facility in Tempe, AZ, owned and operated by Arizona Public Service, which has several PV Hybrid test sites. (See below: ***PV/Hybrid Controller Field Test***). One was also installed at the Sandia National Laboratories Photovoltaics System Evaluation Laboratory and is undergoing testing.

The alternative configuration units at the STAR sites have now been operating reliably for almost two years, even during the extremely hot summers at that location. In January 2003, the performance of the two units at STAR was monitored and minor adjustments to hardware and software were made to improve operability.

A third alternative configuration unit was installed with a hybrid system emulator and an AGM VRLA battery in the Photovoltaic Systems Energy Laboratory at Sandia National Labs (SNL), in order to evaluate operability with this type of lead-acid battery. During FY03, efforts include scale-up to a 100kW class alternative configuration unit, plus further refinement and cost reduction of the 5kW prototypes that have been developed thus far.

A low-cost voltage-temperature sensor for each of the modules in a string has been developed and installed on a two-string, 240V Gel VRLA battery in the Distributed Energy Technology Lab (DETL) at SNL. Before the end of CY03, 120 of these sensors will have been installed. The system is currently under shakedown testing with alternative configuration software.

Second Quarter Status

The two 5kW class units that have been under test at STAR continue to function well. Analyses of the data collected in these systems are performed once or twice per week. The analyses sometimes reveal that changes to operating parameters are required. STAR personnel are increasingly implementing these changes.

Voltage-temperature sensors have been installed and are under test on the STAR systems. They are also being installed on the PSEL system. These tests will further validate the innovative concepts being used in these sensors, and will lay the groundwork necessary for their use with the first high power unit. In addition, bypass switches have been developed, fabricated, and installed on the alternative configuration units at STAR. These bypass switches should negate any deleterious effects from failures within the alternative configuration units, and are believed to be a necessary component of high power units. They also provide a simple mechanism to test performance of hybrid power systems with and without the alternative configuration units. Such "before and after" testing is scheduled for the third quarter of FY03.

Additionally, full operation of the 5kW class unit being tested with a VRLA at PSEL (SNL) has been implemented successfully. Minor software modifications were found necessary as a result of testing of these 5kW class systems and, together with those written for the gel battery at DETL, have been implemented on all systems.

The voltage-temperature sensors needed for the first high power alternative configuration unit have been under test at DETL throughout this quarter. Some minor modifications to the hardware and software were found to be necessary for proper operation of the units; but these now appear to be functioning as necessary.

Development of the design for a high power (100kW class) alternative configuration prototype was completed during this quarter. The design to be used for the first few high power units will utilize high voltage MOSFETs as the main switching elements of the ACONF, and also incorporate a novel approach for providing power for finish charging. The first of the high power units will include switching elements for two strings, and will thus be rated at 33kW continuous. This first unit is to be tested with the two-string Gel VRLA at DETL, using a battery with a nominal voltage of 240V.

Completion of the fabrication and shakedown of the first high power alternative configuration unit is scheduled for the end of the third quarter of FY03. Preliminary development of an alternative configuration applicable to standby-power systems using batteries is also underway. The first test of such a unit, at a 5kW class scale, is planned for the end of the year.

↑ Table of Contents

RAPS Testing Methods

The DOE ESS Program at Sandia continues to coordinate with the International Lead Zinc Research Organization (ILZRO) on a project to define standard test-cycle regimes for remote-area power supply (RAPS) systems. In FY99, a major decision was made to integrate this project with the existing infrastructure of the Institute of Electrical and Electronics Engineers (IEEE) Standards Coordinating Committee (SCC) 21, Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage. The documents in process in the Energy Storage Subsystems

Working Group (ESSWG) of SCC 21 all relate to distributed energy resource energy systems with battery storage used in a stand-alone mode (no utility connection).

Sandia, ILZRO, and Energetics Inc., a contractor to SNL on this project, are coordinating the activities of the ESSWG and are preparing new guidelines for RAPS systems–those that use a renewable generation resource, energy storage, and a fossil-fueled generator in a stand-alone mode. Work is in progress on two Project Authorization Requests (PARs):

PAR 1361 – Guide for Selection, Charging, Test and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic Systems (Draft 15)

PAR 1561 – Draft Guide for Sizing Stand-Alone Energy Systems (Draft 6)

Second Quarter Status

PAR 1361 — The ESSWG completed a draft of PAR 1361 during its meeting in February 2003, at the Arizona Public Service (APS) Solar Test & Research (STAR) Center in Tempe, Arizona. That draft is now in the hands of the IEEE-SA Standards Board Review Committee (RevCom), a committee of 30 to 40 people.

RevCom makes recommendations on the approval or disapproval of standards submitted to the IEEE-SA Standards Board. Among other items, RevCom verifies that the document matches the PAR objectives and scope. The ESSWG does not anticipate any problems with RevCom or the Standards Board review for PAR 1361.

The Standards Board meets at the end of March or early April. They will assign an editor (for non-technical changes) and the document is slated for publication around June 2003.

PAR 1561 — Work on the PAR 1561 document focused primarily on clarifying definitions and terminology and coordinating action items between working group members and various industry experts.

Under consideration for a while now has been a change in the title for PAR 1561. Group members thought that the document would be more aptly named "Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Hybrid Remote Area Power Supply Systems." A new PAR reflecting the name change was considered.

Reconciling some of the language that appears in 1561 and other PARs was also a topic of discussion.

The group discussed adding a section in 1561 on life cycle cost analysis, including a software "calculator" as part of the standard, noting that the Internet is an ideal environment for such a tool. Contact will be made with the IEEE regarding the rules about web-based tools as part of the standard.

Current PAR activity and status information can be found on the working group's web site www.energetics.com/ieee (username: scc21; password: eswgtest), which Energetics developed and is maintaining. The evolving site currently has several existing links, but could potentially link to an even greater number of participating groups and organizations, which would allow members to coordinate related efforts and to use the environment as a "clearinghouse" of member information (e.g., PAR draft status, current iterations, and updates reflecting significant member changes).

↑ Table of Contents

Peru System Monitoring

In July 1997, the International Lead-Zinc Research Organization (ILZRO), the U.S. Solar Energy Industries Association (SEIA), and the Ministry of Energy and Mines of the government of Peru signed a Memorandum Of Understanding (MOU) for a collaborative project to design, install, and operate advanced, remote area power supply (RAPS) systems, which include lead-acid batteries, in isolated off-grid locations.

The goal of this pilot project is to demonstrate that battery-based hybrid power systems could be technically and financially viable options for rural, off-grid electrification. This goal applies to not only the technical aspects of the equipment but also the social and economic development needs of rural, remote communities.

The first phase of the project was a feasibility study for photovoltaics in combination with storage, power electronics, and controls for use in remote villages along the Amazon River valley, and included an estimation of the economic benefits. The MOU signatories and the ESS Program shared the cost of the study. An ILZRO report documents the results.

With funding provided by DOE/ESS and ILZRO (through the Peruvian government, the World Bank and other financial institutions), the project entered the hardware development and installation phase near the end of FY01, which has continued throughout FY02 and into early FY03. Orion Energy of Frederick, MD, is the system integrator for all the equipment and has been developing the data acquisition system (DAS) with DOE/ESS support.

Two villages have been selected to serve as prototype test sites: one with a 30 kWp electric system (Padre Cocha in the Loreto Province of Peru) and another with a 60 kWp system (Indiana; also in Loreto Province).

Second Quarter Status

All of the RAPS equipment, including the PV modules, for the smaller (30-kWp) system at Padre Cocha, is at the site. The array will be installed by the end of April and full system start-up is planned for mid-May.

Until the smaller system has been successfully demonstrated, the Peruvian government has decided not to purchase an array for the larger system (60 kWp) intended for the Indiana site. A successful test will be characterized by three months of trouble-free operation at Padre Cocha.

An inauguration ceremony is scheduled for around June 15, 2003. Peru's president, Alejandro Toledo, has been invited.

↑ Table of Contents

Vernon & Metlakatla VRLA Battery Monitoring

VRLA battery systems have been in place at the GNB Battery Recycling Facility in Vernon, California and at Metlakatla, Alaska for several years. The BESS at the Vernon smelter, a battery-recycling center, was first installed in 1995. It consists of two strings of 378 cells each of

4800-Ah Absolytes (9600-Ah on site). The BESS for Metlakala Power and Light (MP&L) was installed in 1996 and consists of one string of 378 cells of 3600-Ah Absolytes.

Both batteries have now reached an age where it is desirable to do more extensive monitoring of their condition and operation to determine whether life expectations are being met. A contract has been placed to continue monitoring battery performance at Vernon and begin a more formal tracking of operational data at Metlakatla.

The different use profiles in the two locations provide a unique opportunity to compare two very similar types of VRLA cells in different use environments. In addition, periodic postmortems of modules returned to GNB from both locations will be resumed to assess how much degradation has occurred and estimate the remaining battery life. Only cells from MP&L have previously been removed and returned to the lab for testing.

Second Quarter Status

Both BESS units are on-line. On weekdays, during peak demand times (currently 16:00 to 22:00 PST), Vernon is peak shaving at 3150 kW. Metlakatla is always on-line and reducing fuel consumption on the island to virtually zero. For reasons known only to GE (the system builder and integrator) the software at Metlakatla is different than that at Vernon and does not support file writing.

The Vernon BESS had problems with the GE limit amps, an integral electronic component that serves to filter, limit and balance the amount of current going from the BESS inverters to the substation on its way to the plant. For an unknown period of time, the limit amps prevented the operation of the BESS. GE, the company that performs service on the electronics, has recently repaired them and peak shaving has resumed. .

The cell type employed in the Vernon BESS is not sold in high volume (flame retardant jar/cover material); therefore, manufacture of replacement cells has been delayed. Cells will be available in the early part of May 2003, at which time activities should resume. Consequently, the replacement, testing and analysis activities analogous to those occurring with the MP&L BESS will be delayed for Vernon.

Extensive electrical testing of the 100A25 cell samples culled from the Metlakatla BESS has been completed according to the designed test procedure. Results of capacity tests on the cells when they were cycled at an 8-hour rate to 1.75 volts per cell (VPC) were shown in the last quarterly report. Six of the cells were checked for compliance at several other rates as well. Those results are tabulated below.

MP&L Rate Compliance Testing

	Percentage of Rated Capacity				
Cell	**5-h**	**12-h**	**3-h**	**8-h**	**1-h**
66 C	98%	95%	95%	98%	90%
66 L	96%	96%	97%	99%	90%
66 R	97%	95%	99%	98%	96%
69 L	94%	93%	95%	95%	93%
69 R	100%	98%	105%	101%	107%
69 C	95%	93%	98%	97%	100%
Average	**97%**	**95%**	**98%**	**98%**	**96%**

Clearly, the cells are performing extremely well after seven years in a partial charge application. Even at rates as high as the 1-hour rate, compliance to the published capacity ratings is excellent.

In service, the cells are being operated at approximately 75% SOC. Yet, apparently, the cells are not being damaged by this environment and can be brought up to fully rated capacity. Exide/GNB considers this to be more data that validates the design and attests to the robustness of the Absolyte product in difficult applications. According to the test procedure, the cells should also have been charged at 2.25 VPC to characterize their float behavior. A program glitch caused this step to be skipped, but this test is being done starting the week of March 31.

A tear down of the MP&L cells will occur on 10 April. Plate test samples will be retained for additional chemical and/or x-ray diffraction testing.

The teardown activities during next quarter will provide another piece of the puzzle regarding remaining life expectancy of Absolyte batteries subjected to this unusual charge regime.

↑ Table of Contents

PV/Hybrid Controller Field Test

The ESS Program owns a large CR9000 Data Acquisition System (DAS), located at the APS STAR facility (Arizona Public Service Solar Test and Research Center) Hybrid Test Facility located on a remote mountaintop, approximately 106 miles from Tempe. This DAS is currently on loan to APS to assist them in evaluating off-grid hybrid systems being tested at the APS STAR Hybrid Test Facility. In return, APS has agreed to share test results to increase our database on off-grid hybrids. ASU is responsible for the operation and maintenance of the DOE-owned DAS and is responsible for all data management activities and limited analytical support for data collected.

In addition, ASU STAR and SNL have been collecting data and monitoring activity on the Alternative Configuration project under test at STAR (See above: ***Alternative RGS System Designs to Improve Battery Performance)***. ASU is tasked with all data management activities associated with this activity.

Sandia also continues to consult with the APS STAR team on activity at Carol Springs Mountain (CSM), following the re-powering of the energy storage system with Absolyte IIP batteries. The CSM system consists of a 26 kW PV array, a 53 kW diesel generator, a 30 kW AES bi-directional inverter, and a 600 kWh Absolyte IIP VRLA battery configured in three parallel, 200 kWh strings. The average load at the remote telecommunications site is approximately 17 kW. Sandia has a DAS installed at the CSM site that provides operational data to both APS and Sandia.

Because of SNL's interest in analyzing the performance of an Absolyte IIP battery from its commissioning until its shut-down, APS has provided a unique opportunity to complete a lifetime analysis on a large battery. As a result, SNL has entered into an agreement with APS to provide monitoring and data management for the new battery and has developed a plan for the ASU Team to perform these activities under the current APS contract. Initially, the battery was tested for system integrity with the use of ohmic measurement devices as a baseline record for the battery. Data acquisition and archival for monitoring battery performance throughout its life is in progress.

Second Quarter Status

Throughout this quarter, ohmic measurements were taken and analyzed for CSM. The battery continues to perform without incident.

Voltage/temperature sensors were installed on all batteries operating in the Alternative Configuration test projects at STAR. The purpose of the sensors is to provide information that will allow management of the battery based on the cell that exhibits the highest stress during charging and discharging operations. This management strategy will result in the increase of overall battery performance and will extend the life of the battery.

The test program continues to collect, analyze, and archive data from the two off-grid systems undergoing testing at STAR.

↑ Table of Contents

Data Analysis from PV/Hybrid Controller Testing

For the past two years, data has been collected and archived by Arizona State University (ASU) at the Arizona Public Service (APS) Solar Test and Research (STAR) Center Hybrid System Test Facility, using a Data Acquisition System (DAS) supplied and maintained by SNL (See: ***PV/Hybrid Controller Field Test***, above).

EECI is the primary analyst and consultant for the project and is responsible for generating quarterly reports that evaluate the effectiveness of the operational strategies employed at the Hybrid System Test Facility. Tracking the life history of the Yuasa tubular gel battery currently on loan to Sandia DETL by APS has been a primary task for EECI. Plans are currently underway to install an Alternative Configuration (ACONF) controller on the battery at the DETL. This will be the first 240 VDC system managed by the ACONF system.

Second Quarter Status

The Yuasa battery has been routinely cycled using the Trace 30kW inverter, which will be the primary inverter for the test program that includes testing for both the Yuasa tubular gel battery and the high voltage ACONF controller. Final preparations for the installation of the ACONF were completed during this quarter.

During this quarter the installation of 120 voltage/temperature sensors on the 240-cell Yuasa battery was completed. The ACONF unit will use these sensors during the testing of the high power ACONF unit.

↑ Table of Contents

Integration & Testing of Energy Storage with Flexible AC Transmission System (FACTS) Devices

The purpose of this project is to explore the operational enhancement of a power transmission system by integrating a Battery Energy Storage System (BESS) into a variety of Flexible AC Transmission System (FACTS) devices.

FACTS devices are power-electronic-based controllers to enhance controllability and increase power transfer capability in a bulk power system. Currently, there is a general lack of understanding about how to effectively incorporate energy storage into existing FACTS topologies.

Specifically, this project is addressing:

- Proposed control strategies for voltage control, dynamic stability, and transmission capability improvement;
- Comparisons of simulation and experimental results of integrated FACTS/BESS systems;
- Comparisons of the performance of different FACTS/BESS combinations; and
- Comparisons of the performance of different converter topologies, such as multilevel techniques.

Thus far, results have established the viability of using FACTS/BESS to enhance bulk power system operations. Several controls have been proposed, via simulation and experimental verification, which are effective in transmission capacity control, voltage control, and oscillation damping.

Second Quarter Status

Work has concentrated on further development of the multi-level converter topologies for various FACTS/BESS systems. Multilevel topologies offer improved voltage quality, decreased switching frequencies, and decreased voltage stress and power losses on the individual devices. One disadvantage of the conventional StatCom/BESS is that the battery voltage can be too high for practical use in transmission-level applications.

One approach to decreasing the required BESS voltage is to replace the standard voltage-source-converter (VSC) with a multi-level inverter. Two multi-level inverter structures that have been investigated are the cascaded inverter and the diode-clamped inverter. Both converters have shown excellent dynamic response comparable to a traditional StatCom/BESS.

Cascaded Multi-level StatCom/BESS

The cascaded multi-level converter uses several full bridges in series to synthesize staircase waveforms. Because every full bridge can have three output voltages with different switching combinations, the number of output voltage levels is $2N+1$ (N is the number of full bridges in every phase). For active power conversion, this topology needs separate DC sources. The structure of separate DC sources is suitable for energy storage devices such as batteries, since it provides the advantage of using batteries of lower voltages as opposed to non-cascaded topologies. Additionally, a cascaded converter connected with a BESS does not have a capacitor voltage-balancing problem.

The hardware for the cascaded multi-level StatCom/BESS has been constructed. A sample of the non-filtered output voltage of the PWM-controlled multilevel StatCom/BESS is shown in Figure 1. This waveform indicates that hardware and PWM control are working within specifications. The next step is to link the PWM with a system control.

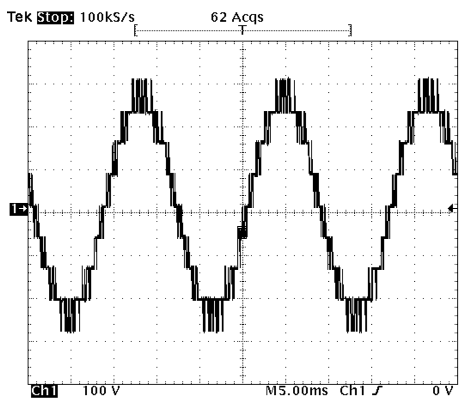


Figure 1: Line-to-Line output voltage for the 5-level, PWM-based cascaded converter.

Diode-Clamped Multi-level StatCom/BESS (Figure 2.)

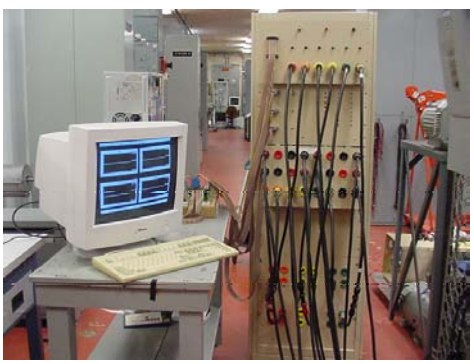


Figure 2. Diodeclamped StatCom/BESS

One advantage of the diode-clamped configuration is that there is no possibility of simultaneous operation of the series switches ("shoot through").

The diode-clamped topology does not require as many separate DC sources (batteries) as does the cascaded multi-level converter, if a proper voltage balancing circuit is utilized. The traditional sine-triangle PWM scheme cannot balance the voltages; however, a PWM control based on space vector modulation can be effectively utilized to balance the voltages among the batteries and capacitors used as DC sources.

FACTS Interaction

Another area of study is whether or not FACTS devices can adversely interact with each other. Recent analysis has shown that devices that are located in close proximity might indeed interact and cause system instability. Figure 3(a) shows the system response to a short circuit. The generator speeds respond with poorly damped oscillations, but still remain stable.

However, the introduction of FACTS devices in the system can actually cause this system to become unstable. Figure 3(b) shows the generator frequencies of three generators that are obviously becoming unstable as a result of the FACTS devices. A new, fuzzy logic-based controller was developed that can counteract the interaction and provide additional damping to the system. The results are shown in Figure 3(c).

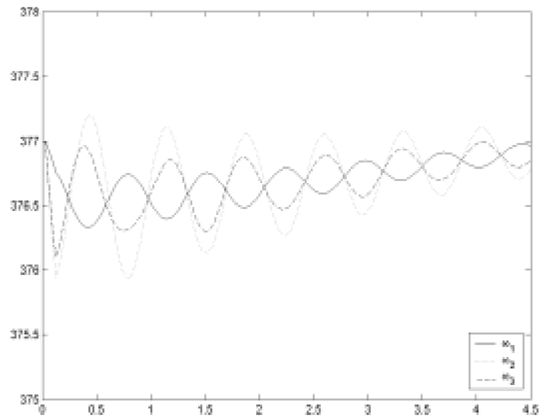


Figure 3a. System response to a short circuit

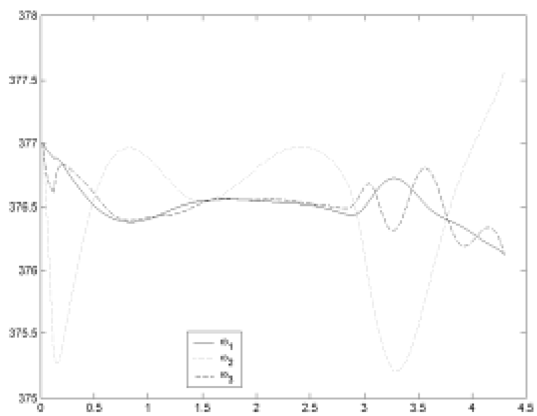


Figure 3b. Instability of three generators due to FACTS device

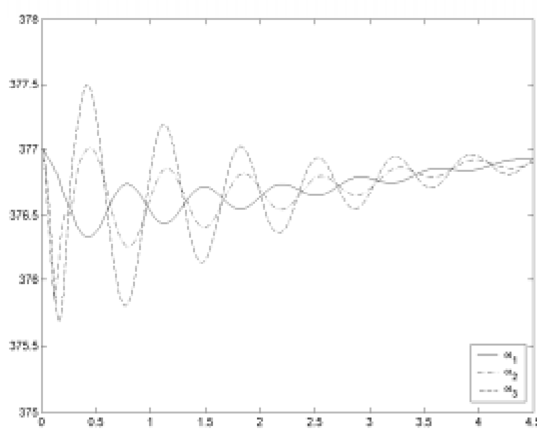


Figure 3c. Stability imposed by fuzzy logic-based controller

↑ Table of Contents

Natural Gas-Fueled, 5kW, Continuous Power Fuel Cell

Late in FY02, under a "cradle-to-grave" procurement contract with Plug Power, a 5 kW Plug Power SU1 CHP (combined heat and power) fuel cell was delivered to the Distributed Energy Test Laboratory (DETL) at SNL. The fuel cell has the capability to operate grid-tied or stand-alone, and it is to be operated and tested in both configurations.

The contract contains a provision for training two Sandia personnel in the operation and maintenance of the system. Following training, the Sandia personnel will install, operate, and maintain the system at the DETL, with technical support provided by Plug Power.

The purpose of this program is to characterize the fuel cell for operations above 5000 ft altitude and provide performance data for both on- and off-grid operations. The fuel cell will also become a power generation component in the DER test program and will be connected to the DETL Micro Grid after characterization is complete.

During the third year of the contract, the system will be upgraded to the most recent advancements in hardware and software to maintain the system at state-of-the-art status.

Second Quarter Status

The Plug Power SU1 CHP fuel cell was fully installed in the DETL early in this quarter. Start-up was delayed because of ES&H compliance issues unrelated to the fuel cell.

On February 20, 2003, the unit was brought on-line at an output of 2.5 kW, with the power being dispatched to the grid. Final test plans were coordinated with Plug Power.

Shake-down testing is planned that will replicate the factory acceptance tests for the purpose of characterizing the operation of the unit at high altitude, as compared to testing in Albany, NY. This test is scheduled for early in the third quarter, following a run-in of four-six weeks of mid-power operation.

↑ Table of Contents

Hardware Prototype of Device to Improve Transient Loadability of Distributed Energy Resources (DER)

The purpose of this project is to develop a laboratory prototype for an energy storage-based device that will improve transient loadability of Distributed Energy Resources (DER). Under a FY02 contract, NMSU has fabricated a single-phase prototype for this device and disclosed a Technical Advance with Sandia.

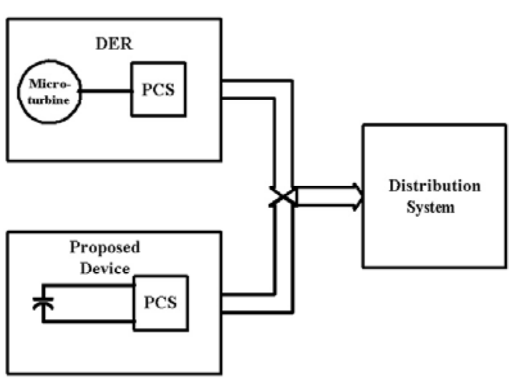


Figure 1. Proposed Device To Improve the Transient Loadability of a DER

As shown in Figure 1, an electro-chemical capacitor is interfaced to the DER terminals using a simple, short-term rated, dc-ac inverter. At the onset of a large transient load current (Motor Current), the capacitor supplies the excess current needed (Device Current). As a result, the DER need not supply the entire transient current.

Thus, the DER operates below its current limit and can ride out the disturbance.

During the first quarter of FY03, the operation of the basic prototype was tested with different types of capacitors, including conventional electrolytic capacitors, double-layer capacitors (Maxwell), electro-chemical capacitors (ESMA), and a newer hybrid `technology (Evans).

Second Quarter Status

During this quarter, the design of a three-phase prototype was completed for three-phase testing (Figure 2). Needed extensions to the control algorithm for the three-phase system were also developed. NMSU fabricated a circuit board. The new prototype will be tested with the available capacitors in the third quarter of this year.

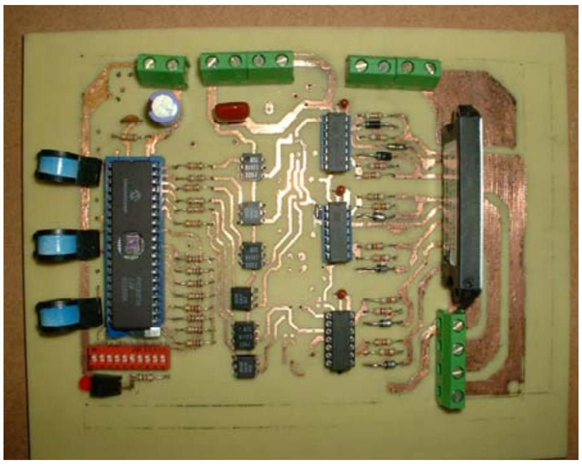


Figure 2. Three-phase Circuit Board for Proposed Device

The experimental prototype has provided a 'proof of concept" for a device that can assist DER in handling transient loads.

↑ Table of Contents

Apparatus for Testing Charge/Discharge Characteristics of Supercapacitors — NMSU Capstone Design Project

Supported by the DOE ESS Program, and managed by Sandia National Laboratories (SNL), the Klipsch School of Electrical and Computer Engineering at New Mexico State University offered a "Capstone Design" class to senior undergraduates during the Summer/Fall 2002 semesters.

The Klipsch School requires that all BSEE students complete a six-credit Capstone Design class. Students with senior standing must design a reasonably complex system, drawing upon several specialties such as power, electronics, computers, control, etc. The class provides significant experience in teamwork, written and oral communication, and leadership experience for the students.

DOE has an interest in the use of electrochemical and double-layered capacitors (so-called 'Super-capacitors', or 'Ultra-capacitors'), as energy storage media in power system applications. NMSU developed and offered a Capstone class in which students were tasked to design a "Super-capacitor Test System." Specifically, the system would be used to study charge/discharge characteristics of super-capacitors. The system would consist of the following components:

- Power electronics suitable for charging and discharging super-capacitors according to a specified protocol;
- A user interface based on National Instruments hardware and Labview software; and
- Necessary software to implement specific protocols such as constant power discharge.

The interface must allow the user to select and run test protocols, collect and display voltage, current, power and energy waveforms, and calculate and display performance metrics.

Second Quarter Status

A project description was submitted to the undergraduate studies committee. Several students have expressed interest in the project. However, because of the need to complete pre-requisite classes, the capstone design will be undertaken during the summer session, starting about May 20, 2003.

↑ Table of Contents

Li Ion BESS

This project is part of the ESS Program's advanced energy storage (AES) component development initiative. The purpose of the initiative is to support the improvement of AES components (such as flywheels, superconducting magnetic energy storage (SMES), and electrochemical capacitors). The ultimate goal of the initiative is to develop and test AES components large enough to be used in field demonstrations and to find industry partners to support these field demonstrations (including cost sharing).

The immediate goal of this project is to design and construct a 100 kW/1 minute (1.67 kWh) lithium-ion (Li-ion) battery energy storage system for use in providing power quality for grid-connected microturbines.

Portable Li-ion batteries are widely available for a variety of commercial applications (cell phones, laptop computers, etc.). However, larger cells and batteries based on Li-ion technology are still in the early stages of development. Consequently, although commercially available battery technologies were not included in the scope of the AES initiative, SAFT's proposal for an energy storage system based on Li-ion batteries was accepted because it represented the significant further development of an advanced battery technology that was not commercially available for non-portable applications.

The main advantages of a Li-ion system over conventional batteries are its high-energy density and good cycle life (for both deep-discharge cycling and shallow cycling). Additionally, compared to conventional battery systems, Li-ion systems are relatively low maintenance. Although they do require monitoring to prevent overcharging, to a large extent this monitoring can be accomplished with computer technology, as opposed to maintenance, which requires relatively expensive human labor.

The work completed during this project should help to realize the advantages of Li-ion technology for applications where more traditional battery types (specifically lead-acid) are now used. Further, it is hoped that, with wider use in larger applications, this technology can eventually compete with lead-acid batteries on a cost per life cycle basis.

Second Quarter Status

- The partners (SAFT, SatCon, and the utilities) attended a meeting hosted by SatCon in late March. At the meeting, results of the abuse testing for both individual cells and the battery modules were reviewed; the PCS, which was modified to include data acquisition capability, was demonstrated, and a draft of the battery operating manual was presented.
- At the meeting, it was requested that the operating manual be revised to include installation guidelines, minimum ventilation requirements, MSDS information, and other information necessary for proper installation and start-up of the battery. Copies of the manual will be provided to all partners when it is finalized.
- Modifications to the battery software to address an issue with the battery's "sleeping mode" and to the PCS software to allow for more real-time data acquisition and for more flexibility in data storage options were also requested.
- SAFT was asked to request that the USABC release more detailed abuse-testing information (including the test protocol and video) to the partners.

When the operating manual has been corrected and the modifications to the software have been made and tested, integrated systems (battery and PCS) will be shipped to Southern Co. and AEP (the end of April 2003 is the target). Utility integration and system start-up are expected to begin in mid-May.

↑ Table of Contents

Evaluation of Utility Scale System — TVA Monitoring

The Tennessee Valley Authority (TVA) is constructing a large-scale, battery-like power storage facility designed to store electricity during off-peak periods and retrieve it for use when the need for power increases. Using technology developed and provided by Regenesys™ Technologies Limited, of the United Kingdom, the plant is designed to store up to 120 megawatt-hours of energy and provide power for 10 hours.

Initiated in FY02, this project is designed to provide the data collection management, data and economic analyses, and dissemination of the data on the performance of the TVA Regenesys™ Electrical Energy Storage System.

In June 2002, A Nondisclosure Agreement between TVA and SNL was signed, and a Memo of Understanding between TVA and SNL was issued in August 2002. A contract was issued to TVA and Electrotek in November 2002 to perform the data and economic analysis and determine what, if any, modifications/additional equipment to the DAS are required for the analyses.

Sandia also issued a contract to TVA to use their contractors for making any necessary modifications to the existing facility and DAS.

Second Quarter Status

A meeting to kick off the monitoring project was held at the TVA Regenesys plant site in Columbus, Mississippi on 2/19/03.

The goals of the monitoring project were reviewed:

- To look at the entire system as a black box power storage system and gather the data necessary to characterize it's operating characteristics from both technical and economic points of view in all operating modes;
- To evaluate the impact of facility on power system operation, line loading, and capacity;
- To evaluate the impact of the facility on power system quality and reliability; and
- To be able to extrapolate project results for future plants.

Input was solicited from TVA as to what they are expecting to learn from the monitoring project and ensuing data analysis. Some key points discussed included:

- Identify the value streams – which operating modes are more important and why (e.g. arbitrage, time shift, ancillary services, a combination, etc.);
- Determine how well the plant performs while providing these various services (identify limitations and constraints);
- Determine availability and reliability;
- Determine overall plant efficiency;
- Repeat identical tests over time to determine if there is any degradation of the system;
- Determine how energy storage might fit into the standard market design;
- Identify how Regenesys™ technology might be employed to augment intermittent renewable resources (e.g. wind, photovoltaics); and
- Help identify attributes necessary for TVA to decide on when/where to deploy similar plants.

The meeting included a tour of the facility. Below are pictures from the tour.

Regenesys™

Figure 1: Construction progress on Regenesys at TVA site 2/19/03

Figure 2: Cell piping

Figure 3: First floor electrolyte piping.

↑ Table of Contents

NAS™ Battery Demonstration Monitoring

The goal of this project is to obtain, analyze, and disseminate data on the performance of the Sodium Sulfur (NAS™) battery electrical energy storage system currently being installed at an American Electric Power (AEP) site, in Gahanna, OH, a suburb of Columbus. The demonstration is composed of two NGK Insulators Ltd., NAS battery modules that will provide up to 500 kW of power quality protection for five minutes, plus 100 kW of peak shaving capacity for seven hours per day.

A Nondisclosure Agreement between AEP and SNL was signed in July 2002. An Umbrella Memo of Understanding between TVA and SNL, agreeing to work together on this project and other projects of mutual interest, was issued in September 2002. A contract to purchase data was issued to AEP in November 2002.

Second Quarter Status

In January 2003 a contract was awarded to Gridwise Engineering to perform the data and economic analyses.

On March 12, representatives of Sandia National Laboratories, AEP, Gridwise Engineering, and Endecon Engineering held a "kickoff" meeting at AEP for the monitoring project. The meeting began with a tour of the Gahanna PCS/NAS demonstration site. AEP then gave a detailed presentation of the DAS design and operational characteristics of the system.

The goals of the monitoring project were reviewed, and it was clarified that Gridwise will perform a reliability analysis related to the power quality service. AEP requested that the analysis include some indicator that reflects loss of life.

The economic analysis will also be expanded, to include additional NAS applications at AEP:

- Peak shaving (customer) / Power quality
- Peak shaving (utility) / Power quality
- Spinning reserve / Power quality
- Voltage support / Power quality
- T&D Deferral / Power quality

Gridwise will prepare their project plan based on the results from this meeting.

Below are views of the NAS battery installed at Gahanna.

NAS Battery installed at AEP.

NAS battery during installation at AEP Gahanna site.

Table of Contents

Sub-System Development

Super Conducting Flywheel Development

The immediate goal of this project is to produce a 3-5kWh flywheel energy storage system for use in a hybrid wind/diesel generation application. This is the second part of a multi-phase design and development effort between the ESS program and Boeing to mature a new class of flywheel systems with multi-hour storage capabilities. It is being carried out in close conjunction with research into the development of superconducting bearing technology conducted under the Super Conductivity Partnership Initiative of the DOE Superconductivity Program.

This research offers large potential benefits for future large flywheel systems in terms of system efficiency, as well as capital and operating costs. The project has two primary objectives:

- Investigate a wide range of potential applications for advanced flywheels, leading to the design, fabrication, delivery, and site testing of an application-specific flywheel unit of 3 kWh capacity and a power output of at least 12 kW; and
- Develop the material, component, and system technologies that support building this demonstration unit, while laying the foundation for long-term progress in flywheel energy storage.

To accomplish these objectives, the contract specifies the following six tasks:

Task1: Perform high-speed test and characterization of the low-cost rotor/bearing approach developed in FY00. For this approach, the system will store 1kWh with a high safety factor at 24,000 rpm.

Task 2: Down select from the candidate applications to a single target application.

Task 3: Develop a preliminary system design (including construction of a demo unit) for the chosen application.

Task 4: Develop a rim qualification plan and conduct supporting materials testing.

Task 5: Communicate program results and progress.

Task 6: Grow superconducting crystals and use them to construct an array for the demo unit's magnetic bearing. (This task was added to the original contract during FY02)

Tasks 1 and 2 were completed during FY02.

Second Quarter Status

Task 3: The Alaska Energy Authority (AEA) is in the process of gathering load profiles to help define a flywheel system for hybrid wind/diesel generation systems used for village power. Initial investigations indicate that a system delivering several 10's of kW for one to five minutes would be very beneficial in reducing the cycling and fuel consumption of the diesel components of these hybrid systems.

Specific test sites will be suggested, beginning with a less remote test (i.e., road-accessible and near Anchorage), followed by a longer-term remote installation. The State of Alaska might provide some funding to help pay for site preparation, installation, and local supervision of the project by AEA.

A preliminary System Requirements Document was prepared to provide more specific information on the hardware that Boeing can provide for the system. The document details provisional specifications (electrical, mechanical) for a 5 kWh/50 kW flywheel storage system. The document also outlines the process for designing the flywheel system, describes the testing validation/verification philosophy, and defines the preliminary design requirements. Brief sections also describe installation options, operation and maintenance procedures, and data collection methods. Review copies were provided to AEA and SNL.

Procurement of the system's rim and hub continued and the complete component should be ready at the end of May 2003.

Other design work focused on sizing the pumping system for the flywheel chamber. After evaluating out-gassing data taken on actual components, a small, rugged pump suitable for field-testing was selected.

Task 4: Earlier this year, an alternate hub design was built and tested in a subscale 1 kWh version and spun up with a 3 kW motor to 12,000 rpm. To test the unit at its rated capacity, it is necessary for it to spin at 24,000 rpm. Before conducting testing at this speed, it was necessary to gain a more thorough understanding of the rotor's potential instabilities at high speeds. During this quarter, a rotor dynamics consultant assisted in analyzing the stationary modes of the rotor and in predicting the speed dependence of these modes.

Testing using a dynamics model built with the known geometries and estimated stiffness for bearings and interfaces indicated that changes would be needed in either materials or geometry in order to get the rim up to its fully-rated speed. A simple finite-element model will be built to help to predict the stiffness at the splined interface between the rim and hub (the least understood interface in terms of stiffness), to provide data needed to evaluate the possibility of scaling to larger rotor sizes in the future.

Task 5: A paper titled "*Radial Tensile Test Method for Thick Composite Rings*" (prepared as part of the flywheel materials qualification subcontract with Penn State University) was accepted for presentation to the Society of Experimental Mechanics conference to be held in Charlotte, NC in June 2003.

Task 6: Fabrication of the superconducting crystal array for the systems magnetic bearing was completed.

↑ Table of Contents

High Power (ETO) Semiconductor Switch Development for PCS

This project is a continuation of the project funded by DOE to develop advanced power Emitter Turn-off (ETO)-based converter switches for energy storage systems. The ultimate goal of this project is to develop a low cost/highly reliable/low footprint ETO-based converter to be used in high power utility applications.

Based on successfully developed prototype ETOs, VT developed and tested a Generation-3 ETO switch in FY02, and then demonstrated the 4000A, snubberless turn-off capability of the device. Those tests proved that the ETO can achieve superior performance at lower cost and can use any commercially available GTOs to produce ETO switches.

During the first quarter of FY03, the major portion of work by VT focused on testing the ETO's reliability. To that end, VT conducted additional tests of the Gen-3 ETO in collaboration with the Navy Surface Warfare Center in Philadelphia (See below: ***High Power Semiconductor Switch Performance Testing***) and with the American Competitiveness Institute, also in Philadelphia (See below: ***Manufacturing Process Development for High Power Semiconductor Switch***).

In addition, Virginia Tech is applying Gen-3 ETOs to a utility-sized high power converter project sponsored by the Tennessee Valley Authority. A 1.5 MVA converter has been in continuous operation at 1000A/2kV.

These tests demonstrate the ETO's high power/high frequency capability, thermal handling capability, lower driver power consumption, and high reliability.

Second Quarter Status

High Frequency/High Power Burst Test

One of the most impressive capabilities of the ETO is its ability to handle high frequency turn-on/turn-off pulses. Because of its long storage time, the conventional Gate Turn-Off Thyristor (GTO) has current redistribution across the GTO and current crowding under its emitters, which leads to non-uniform temperature distribution. This situation can rapidly induce hot spots and thermal runaway, leading to GTO failure.

The ETO overcomes this limitation by its short storage time and uniform switch behavior. The heat generated by the conduction loss and switching loss is evenly distributed across the ETO device. Therefore, the ETO can survive during extremely high frequency, high power conditions; as long as its hot junction is at a safe distance from the temperature sensitive junction termination. This capability is very important during power system over-load conditions.

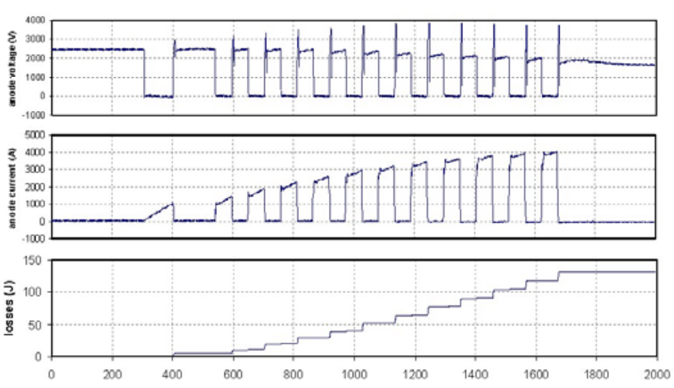


Figure 1. 10 kHz, 12 pulse test with the Gen

Figure 1 shows a 10kHz, 2500V DC bus, and up to 4000A 12-pulse switching test at 25^{o}C. The test results show that the cumulative losses during the pulse sequence are about 130J.

5000A snubberless turn-off capability of the ETO — test and evaluation

The lower density during turn-off transient reaches about 2.387×10^{5} W/cm^2, and the current density during turn-off transient reaches about 99.472 A/ cm^2. These are the highest ever achieved with the ETO devices. This test proves that the ETO already realized its unity turn-off gain concept, and its turn-off limit would be fundamentally same as the Safe Operating Area (SOA) of PNP transistors. Figure 2 shows the ETO 5000A snubberless turn-off waveforms at 2500V DC bus and 25^{o}C junction temperature.

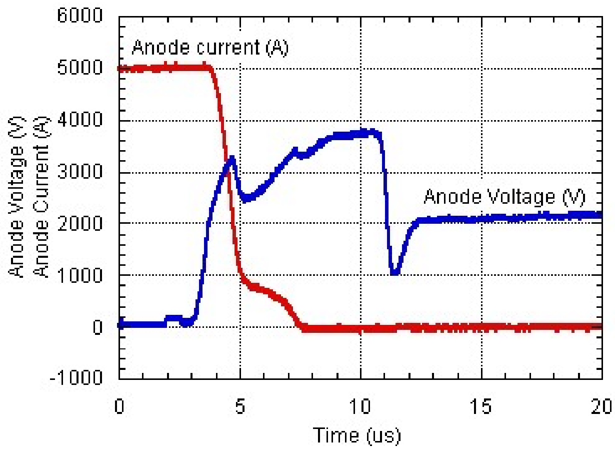


Figure 2. The ETO 5000A snubberless turn off waveforms

Reliability and lifetime of the ETO are improved by optimizing capacitors

The ETO has much lower unit-power consumption than that of the Integrated Gate-Commutated Thyristor (IGCT), and much smaller capacitance is needed to build the ETO circuit. Based on these advantages, the circuit of the ETO can be further optimized. Because much less capacitance is required, all the aluminum electrolytic capacitors are removed from the ETOs, and the much more reliable and longer lifetime, solid tantalum electrolytic capacitors are used. The ETO's failure rate is decreased and its lifetime and the reliability are increased. Figure 3 is the improved ETO that was built using the tantalum capacitors.

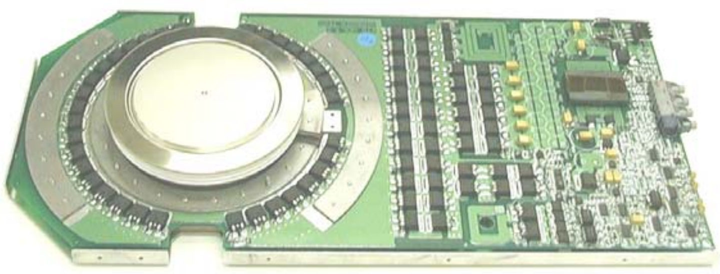


Figure 3. Latest ETO, employing tantalum capacitors.

↑ Table of Contents

ETO Switch Development for PCS Manufacturability

The purpose of this project is to develop the manufacturing processes for the ETO device, a high power semiconductor switch assembly designed by VA Tech (See above: ***High Power (ETO) Semiconductor Switch Development for PCS***). The overall goal is to effectively develop a commercially viable product utilizing the "engineering breadboard" design concept. In pursuit of this goal, ACI's focus has been on:

- Documenting the assembly procedures, processes, and bill of materials;
- Designing the mechanical mounting components;
- Analyzing reliability and production costs; and
- Performing a Finite Element Analysis (FEA) of both thermal and mechanical behavior of the ETO device assembly.

A preliminary specification sheet was produced for the ETO device with the assistance of VA Tech.

During FY02, ACI expanded upon the documentation of assembly procedures, processes, and bills of-material to include all the mechanical mounting components, up through the "top level" assembly.

Utilizing ACI's demonstration factory floor, with the latest state-of-the-art manufacturing equipment, production was increased from one device per day to (potentially) 25 devices per day for the prototype build.

ACI built 24 alpha prototype Generation 3 ETO PCB assemblies and delivered them to VA Tech for evaluation. Two more were subjected to testing at NSWC Carderrock, Philadelphia Naval Shipyard (See below: ***High Power Semiconductor Switch Performance Testing***).

Five ETO PCB assemblies were subjected to thermal stress cycling between +100 degrees C and – 20 degrees C (per JEDEC STD Test Method A106-A, modified). No failures, or any visual consequences, were observed resulting from this test.

Finite Element Analysis (FEA) testing for thermal and mechanical stress of the ETO assembly was performed using ALGOR analysis programs, plus the knowledge/experience gained from the prototype fabrication. This procedure complied with the requirement for water-cooling, necessary to support testing at the Philadelphia Naval Shipyard.

Mechanical parts for ETO assembly were designed using "SOLID WORKS 2001 PLUS" CAD Software, which features a "top-down" design for automated assembly.

The inherent reliability of the ETO assembly was analyzed per the MIL-HDBK-217F standard, using the "parts count method." A cost analysis of the ETO was also derived.

Second Quarter Status

During the second quarter of FY03, ACI initiated testing of the Gen 3 ETO at NSWC Carderrock. The ETO device was damaged during startup, due to a failure of the resistive load bank used in the test setup.

The failure of the initial test was reviewed and documented in a failure analysis report, delivered separately to Virginia Tech and Sandia. Another assembly is currently being outfitted for testing, proposed to begin the last week of April 2003.

Five additional, complete ETO alpha prototypes were produced using these processes and delivered to VA Tech for evaluation, modification, and low power testing, before being returned to ACI for use in the Regional Electric Power Technology Integration and Leveraging Enterprise (REPTILE) Program, high power testing and evaluation (funded under the Office of Naval Research.)

The REPTILE Program supports the Navy advanced surface ship program office (PMS510) with a variety of power electronics projects. One of them is to perform high power level testing of the ETO. Focus is being placed on the thermal cooling techniques, using both water chillers and airflow cooling heat sinks. The case of a single stand-alone ETO device, as well as a stacked assembly of several high power, press-pack devices, was modeled using the ALGOR software to determine such critical parameters as semiconductor wafer junction temperature, load currents, and operating frequencies.

ACI completed a Finite Element Analysis (FEA) for air-cooled thermal and mechanical stress of the ETO assembly, using ALGOR analysis programs and the knowledge and experience gained from fabricating the five additional prototypes. FY03 funding will support completion of this study.

A close working relationship has continued between ACI and the design team at VA Tech as they collaborated on this project. This teamwork expanded in FY03 with the inclusion of Naval Surface Warfare Center personnel, and their capability to perform the high power testing of the ETO prototypes at their Philadelphia facilities.

Significant progress has now been achieved in the movement of the ETO design concept toward a commercially viable product.

↑ Table of Contents

High Power Semiconductor Switch Performance Testing

This project is a joint effort among DOE, Sandia National Laboratories, the US Navy, Virginia Polytechnic Institute, and the American Competitiveness Institute. It focuses on subjecting a prototype power semiconductor device designated the Emitter Turn-off Thyristor (ETO), developed by Virginia Tech, to a series of operational and environmental performance tests (See above: ***High Power (ETO) Switch Development for PCS*** and ***ETO Switch Development for PCS Manufacturability***).

AT NSWC, the device would be subject to 2000 amps at 2000 volts DC during testing, for a four-hour period, at switching frequencies of 500Hz, 1000Hz, and 2000Hz, respectively,. The device would also be subjected to a one-hour thermal cycling test and a long-term environmental test to assess its operation and reliability at extreme conditions.

Figure 1. ETO Device

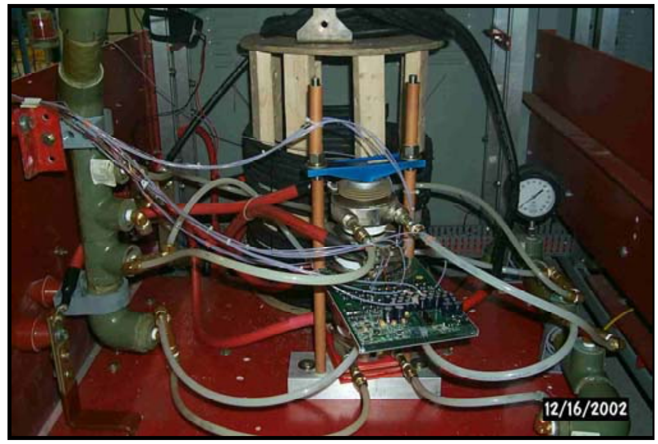


Figure 2- ETO Stack Test Se-up

Begun in August 2002, the initial efforts through December 2002 involved identifying a suitable test location, modeling the test circuit, and procuring, manufacturing, and modifying the necessary circuit components. Test cabinets were installed, facility-wiring modifications completed, and the test device was installed and instrumented.

Second Quarter Status

Final test procedure documentation and the Mission Readiness Panel (MRP) safety review were completed, and testing commenced in January 2003. During the power ram-up phase of the initial test, equipment and measurement anomalies were observed at 500v and testing was halted. A safety mishap occurred when one of the test technicians was shocked by residual voltage (2000V) in the capacitance bank while securing the test circuit. Failure of the resistive load bank at 500V was identified as the source of this residual charge. No further testing was performed during the quarter, pending remedial changes in the circuit design and test procedure.

The test circuit was modified with the addition of a secondary discharge resistor, additional voltage and current sensors, a voltage arrestor, protective fusing, and a snubber circuit. The primary load bank failure was also repaired. Figures 3 and 4 below show the original and modified test circuit.

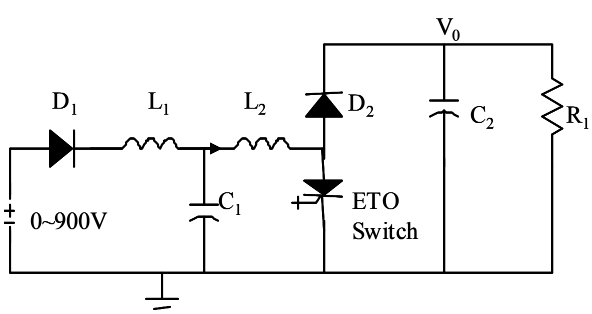


Figure 3 – Original Test Circuit

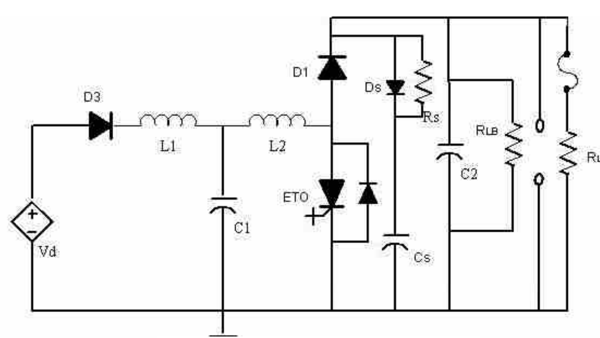


Figure 4 – Revised Test Circuit

Additionally, the ETO test device was removed and inspected to identify components damaged during the voltage transient caused by the load bank failure and not by the ETO device. ACI performed a failure analysis on the damaged board components and the ETO was returned to Virginia Tech for further analysis. A replacement test ETO was assembled, instrumented, and installed into the circuit.

The ETO testing is ongoing and the results of the tests should be available in the third quarter

↑ Table of Contents

Development of an Intelligent Power Conditioning System (PCS) for Renewable Generation Systems (RGS)

In FY00 the ESS Program placed a contract with AEI to develop intelligent system and control strategies for RGS systems.

The conceptual design of a generalized hybrid power system controller was developed during Phase I of the project. In addition, the control strategies and data structure needed to control a hybrid system were defined and "C" code was written for the basic control functions and component models.

In Phase II (FY01), the coding of the hybrid controller was completed, testing of the hybrid controller code begun, actual hybrid hardware system assembled, and the global optimizing software developed. SNL is operating and evaluating the system at its hybrid test facility.

In the first part of 2002, an advanced micro-grid controller entered design phases. Work on this area continued into Phase III of this contract. The Phase III contract was placed on April 24, 2002.

At the end of FY02, sufficient carry-over funds were in place to continue work into the first quarter of FY03.

In the first quarter of FY03, AEI entered Chap 7 bankruptcy proceedings. Liquidation was completed in the second quarter.

Second Quarter Status

All work on this contract has ceased. There are no further deliverables expected under this contract. All funds associated with this contract have been de-obligated.

↑ Table of Contents

Advanced Lead-Acid Battery Improvement Studies

Continued Research & Development (R&D) of Valve Regulated Lead-Acid (VRLA) battery technology is needed to improve system operation performance and reliability in the field. This R&D project is a logical follow-on to the multi-year survey study that was completed in late FY02 on VRLA battery reliability. That study concluded that specific R&D on known areas for technology improvement is well justified, due to the many reliability problems experienced in the field.

Such R&D is underway through the Advanced Lead-Acid Battery Consortium (ALABC) organization organized by ILZRO. The ALABC has a well-rounded research program focused on key technical areas such as separator development, positive electrode improvement, case seal improvement, and charging optimization studies. ALABC, with a total research budget of over $5M per year, is heavily leveraged by a modest ESS investment.

Second Quarter Status

The ALABC has contracted with several groups that have set out to ascertain and to understand the role of separator composition and pore structure in the transport of oxygen from the positive to the negative plate during overcharging. The project has involved an exploration of the physical properties of candidate separator materials with a wide range of pore characteristics (0.1 microns to 10 microns) and an evaluation of the performance of cells (of 70-Ah nominal capacity) containing each of the materials as separators. An aim of the work is to discover if the use of fine-pore separator systems would facilitate the completion of recharge during cycling duty.

Tests were carried out on both a cell design with thin plates (for Starting, Lighting, and Ignition, or SLI, applications) and on one with thick plates (for deep cycle applications). The evaluation included Peukert tests, deep cycle life tests, and float duty measurements.

The unexpected results concluded that the thick plate design provided better high rate performance as the discharge and recharge rates were increased in the Peukert test results, compared to the thin plate cells. In the cycling tests, the thin plate cells all performed very poorly, which suggests that thin plate cells were more prone to failure arising from inadequate compression than were the thick plate cells.

The best cycling performance was achieved by thick plate cells that incorporated all-glass separators with high specific surface area (small pore size). It is possible that, at low separator/plate thickness ratios (i.e. thick plates design), oxygen transport continues to be hindered, even late in life, due to continuing flooding of the separator by electrolyte expelled from the plate pores by overcharge gassing.

Other results were more consistent with expectations:

- The inherent three-dimensional tortuous makeup of absorbed glass mat (AGM) separators allows such materials to retard gas transport even when the materials are dry.
- Multi-layer separators show advantages over simple AGM materials in some applications.
- Separators with poor plate contact result in poor cell performance.
- Thin plate cells containing low surface area AGM separators fail to inhibit gassing during float operation.

The interesting performance of thick plate cells at rates up to around 2C in the deep cycling tests suggests that such cells might also do well in high rate operation, where the range of discharge and recharge is limited (high-rate, partial-state-of-charge operation). Such cells would also be less prone to failure, due to shortcomings in the compressibility characteristics of the separator.

↑ Table of Contents

Trinity Project – Rotor Materials Tests for Flywheels

This project represents the first task in a proposed three-part scale-up effort proposed by AFS Trinity (a flywheel development company) and is part of a cooperative effort between the ESS, AFS Trinity, and the California Energy Commission. The immediate goal of this project is to scale up an existing flywheel system from 100 kW for 15 seconds to 240 kW for 30 seconds.

Initial model flywheel systems indicated that the materials used in the smaller system could not be used in larger systems. Work on this part of the project includes building the smaller flywheel system using new fiber, new matrix material, and a new manufacturing process. Once built, this smaller system will be burst-tested to determine the viability of using the new materials and manufacturing process to produce a larger system.

The ultimate goal for this technology is to develop a large flywheel system capable of storing 2kWh of useful energy.

Second Quarter Status

- After much investigation, it has been determined that rotors made using the new materials cannot be mass produced using TCA's existing manufacturing processes. To date, no modifications to the manufacturing process have been found that would enable production of satisfactory rotors.
- TCA has been able to hand-make rotors using the new materials and has agreed to provide the rotors needed for burst testing. As soon as the rotors are ready, Trinity will proceed with the planned burst testing.
- The results of the burst testing will be used to create computer simulations of how the rotors will perform in a larger system. If the results of the simulations indicate that scale-up is possible, TCA and Trinity will investigate options for mass-producing the rotors.

↑ Table of Contents

Energy Storage Test Systems

During FY02 the Power Source Engineering Dept. (PSED) at SNL contracted with Team Specialty Products (TSP) of Albuquerque, NM, to upgrade Sandia's test equipment to be able to handle energy storage devices up to 48 volts at currents over 250 amps, in order to accommodate testing of a number of new energy storage devices, such as ultra capacitors and Li-ion batteries.

The contract required that TSP produce higher data acquisition rates, improved tester control, and user-friendly interfaces to quickly accommodate a wide variety of test profiles. Specifically:

1) Create a user-friendly cycle profile generator;
2) Increase the number of voltage and temperature data channels to 30;
3) Increase the data acquisition rate; and
4) Create a user-friendly control interface.

The completion of this contract would provide Sandia with high current (>250A) low voltage (<50V) testing capabilities that were previously unavailable and enable Sandia to offer unique in-house testing capabilities for energy storage devices in support of DOE contracts and industry collaborations.

Second Quarter Status

The contract with was TSP successfully completed during this quarter and system testing has begun. This Energy Storage Test Systems project is completed.

↑ Table of Contents

Advanced Hybrid Controller and DG Node Follow-on Effort

Following the bankruptcy of AEI (See above: ***Development of an Intelligent Power Conditioning System (PCS) for Renewable Generation Systems (RGS)***), much of the work on the AHC controller and DG Node was left unfinished. The scope of work remaining could easily be handled by the PI on the AES contract and completion of this work would lead to a completed and fully operational and documented AHC and DGNode. All other follow-on work originally planned for the next phase with AEI has been abandoned at this time.

A contract was placed with Intergrid Consulting (IC) to complete the commissioning of the AHC off-grid hybrid system at the DETL. Other deliverables, such as operating and maintenance manuals, were also included in the IC contract with delivery still pending.

Second Quarter Status

During this quarter, a visit to the DETL was made by Intergrid Consulting that resulted in the final commissioning of the AHC hybrid system. Delays in the receipt of other deliverables under the contract have resulted in the extension of the contract to late May.

Completion of all work is anticipated during the third quarter FY03.

↑ Table of Contents

Optically Isolated Inverters for DER Applications

Airak, Inc., in conjunction with the Center for Power Electronics Systems at Virginia Tech, has developed the first optically isolated/interconnected, high-power, cascaded inverter for Distributed Energy Resource applications, based upon recent advances in optical sensors, optical interconnects, and High-Voltage Integrated Gate Bipolar Transistors (HV-IGBT). Development of stackable topologies enables extremely high power systems to be realized and, when combined with optical voltage and current sensors as well as optical control interfaces, enables a topology that greatly simplifies development within the high-power electronics environment.

The program has been split into two phases. The purpose of the Phase I effort, which administratively concluded February 26th, 2002, was to develop a single-phase prototype, full-bridge megawatt inverter, based upon newly available HV-IGBTs and combine these newly developed topologies with optical sensing, interfacing, and control. Design parameters concerning maximum voltages, currents, harmonics, and switching frequencies were developed and implemented in conjunction with the latest developments in optically based sensors and interconnects.

The Phase II effort, which officially started May 31st, 2002, is focused upon developing a three-phase version of the Phase I inverter system, and then delivering the three-phase system to American Electric Power for testing and certification for grid-connect operations.

This USDOE SBIR Phase II program contract was officially awarded on September 30, 2002, with a start date of May 30, 2002. Airak has received $455K of the anticipated $750K allotted on Phase II SBIR. Virginia Tech's program, the 300 kW power supply, has been cancelled and reassigned to the Airak facility. Airak and American Electric Power (AEP) are in holding status concerning collaborative discussions, and delivery of the inverter product to AEP is currently in question

Second Quarter Status

The following major milestones have been accomplished since the last report:

- Finalized mechanical layout.
- Received all eight ThermaCharge 10 KW heat pipe assemblies.
- Received two of three 850 uF, 3,300 kV capacitors.
- Received cabinets and mechanical hardware for inverter assembly
- Received v1.0 of power PCB for single-phase testing.
- Completed full assembly and initial testing of single-phase 1700 kVA inverter phase leg (Figure 1).
- Completed mechanical assembly of three-phase system (Figure 2).

The following major milestones are anticipated for the third quarter of FY 2003:

- Receipt of 14 CM1200HA-66H 3300 V, 1200 A HV-IGBT and 2 CM1200HA-50H 2500 V, 1200 A HV-IGBTs.
- Receipt of final 850 uF, 3,300 kV capacitors.
- Continued testing of single-phase unit.
- Finalization of the power PCB design and an order for the remaining three.
- Finalization of the gate-drive design and layout.
- Completion of the design and layout of the single-phase control system.
- Completion of the three-phase system assembly with initial testing of each single-phase leg.
- Continued EM-FEA modeling of the inverter phase leg to gain better understanding of EMI and RFI density levels.

- Continued development of the optical current, voltage, and temperature sensor and subsystem.

↑ Table of Contents

Nickel Metal Hydride Bipolar Battery Development

This is a direct, congressionally funded project that began late in the fourth quarter of FY02.

Electro Energy has undertaken the development of a bipolar nickel metal hydride battery whose performance characteristics could meet a variety of energy storage application needs, including high voltage/high power modules having high cycle life. Initially, the goal of this one-year effort was to deliver a single, 50 V module. However, the specifications have since been revised upward, and the renegotiated deliverable is now defined as a 60-cell, 70 V, 6 Ah module capable of supporting 500 A loads (15 kW under load) for approximately 2.5 s.

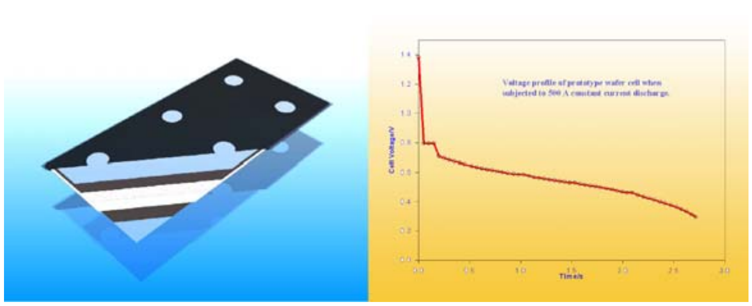
In addition to this final hardware deliverable, other hardware at intermediate states of development will also be provided for independent evaluation.

Among other areas, a technical and commercial market assessment of the general applicability of this system for ESS needs will also be included in this program.

Second Quarter Status

During the first quarter, EEI delivered four prototype cells to Sandia National Laboratories for independent device performance and evaluation. Since then, EEI has fabricated and initiated electrical characterization of a number of the baseline wafer cells that will be used for development of the 70 V bipolar module.

The baseline cell, referred to as a wafer cell (rendering illustrated below left) measures approximately 6-inch X 12-inch X 0.035-inch thick. The nominal capacity of the cell is 6 Ah, and preliminary electrical characterization of these cells clearly demonstrates their high rate capability. The highest current level evaluated was 500 A, and the behavior of a prototype cell under that discharge rate is shown to the right of the cell rendering.



As illustrated by the discharge curve, these cells are able to support a continuous 500 A load, which corresponds to approximately 250 W at the cell level and a projected power of about 15 kW at the module level, assuming a nominal operating voltage of 0.5 V per cell. (The power projection is based on the experimental data; and improvements to the cell design, specifically the end plates, are expected to provide further improvements in the power levels attained.)

Two of the high power prototype wafer cells were delivered to Sandia National Laboratories for independent device evaluation.

↑ Table of Contents

NanoMaterial-Based Electrodes for Energy Storage Devices

This Phase I SBIR activity focuses on new materials development and delivery of a laboratory prototype for energy storage systems.

A new area of materials research and development is centered on the preparation of nano-sized materials. A number of practical reasons exist for this interest, including the possibility of improved and/or enhanced materials properties that will ultimately impact device performance.

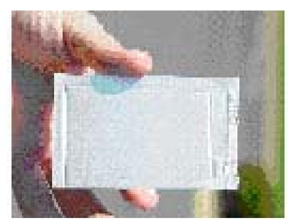
Nanopowder Enterprises is one of the companies that are involved in this new area of materials development, and they have identified candidate nano-materials that could significantly improve the performance characteristics of energy storage systems that utilize these materials.

Toward this end, NEI has embarked on a program designed to prepare and evaluate the behavior of candidate nano-materials that will be used to fabricate a prototype asymmetric hybrid cell.

During the first quarter of FY03, NEI successfully demonstrated processing temperatures as low as 500º C for some of these nano-materials.

Second Quarter Status

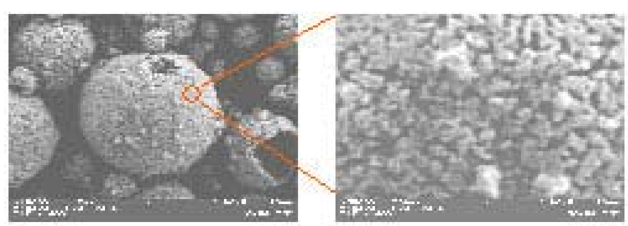
During this quarter two major milestones were achieved. The first involved fabrication of the prototype cell, shown at right. This device is currently undergoing electrical evaluation at NEI.



Photograph of asymmetric laboratory prototype.

The second significant milestone that has taken place this quarter is the development of a procedure for preparing nano-sized WO_2. NEI prepared materials on the order of 50 nm. The scanning electron photomicrograph (below) provides a pictorial example of these nano-materials and how they cluster together to form larger micron-sized particles. This photomicrograph clearly illustrates the spherical nature of the macro-sized clusters and their makeup from nano-sized materials.

Of course, one of the practical considerations and implications of the morphology of nanomaterials, insofar as it relates to device development, concerns material packing in an electrode structure. In this case, the spherical macro-sized material should allow for a more conventional approach to electrode fabrication, while hopefully retaining the benefits of nano-sized materials



SEM photomicrographs at high (left) and low (right) magnification, showing 50 nm nanocrystals (left) and clusters of nanocrystals making up micron-sized clusters (right).

↑ Table of Contents

IEEE SCC-21 Standards Coordinating Committee

It is important for the World Bank and other international funding agencies to ensure minimum standards of performance and reliability in order to protect their investments in technologies.

The IEEE SCC-21 Standards Coordinating Committee on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage is chaired by Richard DeBlasio from NREL; and the working group on PV systems and batteries is chaired by Jay Chamberlin from Sandia Labs.

The goal of the working group is to provide design and test procedures standards for PV systems and batteries.

Second Quarter Status

The PV systems and batteries committee, which is made up of national laboratory, PV and battery industry professionals, is currently working on two documents:

- PAR 1561 — "*Recommended Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Hybrid Remote Area Power Supply Systems*;" Carl Parker of ILZRO (International Lead Zinc Research Organization), task leader; and
- PAR 1526 — "*Recommended Practice for Testing the Performance of Stand-Alone PV Systems*;" Peter McNutt of NREL (National Renewable Energy Laboratory), task leader.

A third document, PAR 1361 — "*Guide For Selection, Charging, Test and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems*," for which Tom Hund from Sandia Labs is task leader, has been approved by the IEEE standards board and is now in final editing before publication.

It is expected that PAR 1526 will be re-balloted and approved soon, while PAR 1561 will require more work in committee.

↑ Table of Contents

Super Capacitor Study

EPRI PEAC is working with ESMA, a Russian ultracapacitor manufacturer, to build energy storage systems for power quality and transmission line stability. Sandia is supporting this work by conducting laboratory testing on the ultracapacitors and the power quality system designed by EPRI PEAC.

The high charge and discharge rates and long cycle-life of the ESMA ultracapacitors could make them an ideal replacement for batteries in power quality, transmission line stability, and hybrid electric vehicle applications that require energy for short time

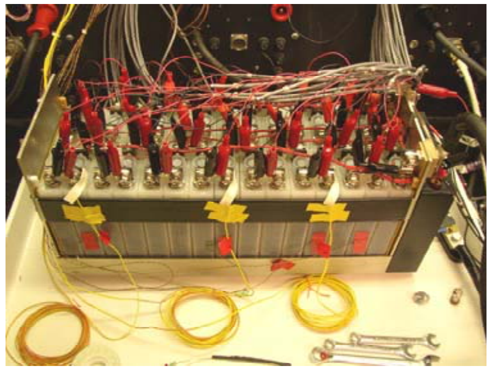


Fig. 1: ESMA Ultracapacitor 30-cell 42-volt 61 Wh Module (30EC402)

durations without the need for frequent replacements due to a low cycle-life.

The ESMA ultracapacitor (Fig. 1) is an electrochemical capacitor consisting of a negative electrode made of activated carbon and a positive electrode made of nickel hydroxide. This capacitor design has a greater specific energy and discharge rate compared to capacitors with two carbon electrodes. Their cycle-life is projected to be 100,000+ cycles, with a recharge time of only a few minutes, or less.

Fig. 2: EPRI PEAC PQ Ultracapacitor 378-Volt 550 Wh Energy Storage System.

A key factor in the success of the ultracapacitor technology is its ability to maintain stable cell voltages within the capacitor cell string. Excessively low cell voltages can result in cell voltage reversals, causing excessive heating or cell damage. To prevent this condition, ESMA has built into their ultracapacitor module a cell voltage leveling-circuit and a module-leveling circuit. The leveling circuits should charge low voltage cells or modules to prevent cell damage.

In the first quarter of FY03, testing was initiated to evaluate the ESMA ultracapacitor performance with and without this cell-leveling circuit. In addition, the 378-volt 550 Wh EPRI PEAC PQ Ultracapacitor system was installed and prepared for testing at Sandia (see Fig. 2).

The test results below indicate a need for the cell-leveling circuit.

Second Quarter Status

Float and open-circuit test results on the ESMA 30-cell ultracapacitor module (30EC402) have provided performance data on cell voltage stability and leveling circuit performance. Compared with a no-leveling circuit, the ESMA cell-leveling circuit works primarily in open-circuit mode in order to maintain a narrow range of cell voltages. In open-circuit mode, the leveling circuit significantly reduced the range of cell voltages (from 1.325 to 1.449 volts down to 0.872 to 0.902 volts, for an end-of-test range of 0.030 volts). Without the leveling circuit, the end-of-test voltage range was 0.363 volts. This is a significant improvement.

In float mode applications the results are not as clear. Cell voltages after 14-days with the leveling circuit on were between 1.371 and 1.449 volts, excluding the low-voltage cell (number 12) at 1.324 volts. This is a range of 0.078 volts, excluding the low-voltage cell. Without the leveling circuit, the voltage range after 14-days was between 1.380 and 1.438 volts excluding the low-voltage cell at 1.281 volts. This is a range of 0.058 volts, excluding the low voltage cell. The cell voltage range without the leveling circuit is less than the range with the leveling circuit on, excluding the low-voltage cell.

The major difference in the two float voltage tests was the higher value of the low-voltage cell at 1.324 vs. 1.281 volts. This indicates that the leveling circuit may not provide sufficient charge for the low-voltage-cell to maintain a stable voltage on float, due to the competing effects of different cell leakage currents.

Future work for this program will focus on the cell-cycle performance and standard test procedures.

↑ Table of Contents

Strategic Analysis

Value of Storage for Restructured Utilities

This project is a continuation of a study initiated in 1998 (Ref: Phase I, SAND2000-1550) that defined several possible electricity-provider scenarios that could use energy storage after the restructuring of the U.S. electric utility industry.

In FY00 (Ref: Phase II, SAND2003-0362), five of the most promising storage market opportunities were selected as having the highest potential to make a substantial impact on the electricity delivery system:

1. Power Cost Volatility
2. Transmission and Distribution Benefits
3. Enhanced Environmental Externalities
4. Combined Heat and Power Output Smoothing
5. Storage System Packaging Breakthroughs

During FY01-FY02 (Phase III), the economics of energy storage were evaluated for a combined application involving arbitrage (buy-low, sell-high) plus T&D deferral as the primary benefits.

In addition to estimating the various financial expenditures and the value of electricity that could be realized in the marketplace, technical characteristics required for grid-connected distributed energy storage (DS) used for generation capacity deferral were also explored**.**

Second Quarter Status

A draft of the report titled "*Innovative Applications of Energy Storage In a Restructured Electricity Marketplace Phase III Final Report*" is in final mark-up and is slated for publication by June 2003.

During this quarter, a draft statement of work (SOW) was written for continued analysis of findings from the Phase III effort. This SOW will be negotiated during the next quarter.

↑ Table of Contents

EESAT2003 (Electric Energy Storage Applications and Technologies Conference)

At EESAT 2002 the participants indicated overwhelmingly that they would prefer to attend EESAT 2003 at the same location. Therefore, the EESAT Committee will present EESAT 2003 in San Francisco, CA at the Sir Francis Drake Hotel on October 27 – 29, 2003.

Second Quarter Status

Preparations are proceeding, as planned. The first call for papers was released this quarter, with a May 2003 deadline.

↑ Table of Contents

PCS Magnetic and Functionality Analysis

During FY00 and FY01, Dr. Satish Ranade, on a consulting basis, provided requested information, resources, and technical insights for interfacing electrical utility systems with energy storage systems. His deliverables were white papers on topics requested by SNL**.**

In FY02, Dr. Ranade focused on issues related to Distributed Energy Resources (DER) and associated Power Conversion Systems (PCS). He addressed two specific topics: 1) the effect of motor starting on the operation of isolated DER; and 2) the modeling of DERs in electric distribution systems.

Typically, under isolated conditions, a DER cannot start moderately large motors because the PCS cannot supply the starting current required. Therefore, Dr. Ranade's research was to examine the use of capacitive energy storage to assist in motor starting.

A scheme based on electro-chemical capacitors and a simple PCS was developed and simulation studies suggest that the scheme can effectively assist the DER with transient loads. The scheme has now been implemented under a separate project as "proof-of-concept."

Second Quarter Status

Dr. Ranade continues to support SNL's effort in the areas of inverter design and capacitor applications in energy storage.

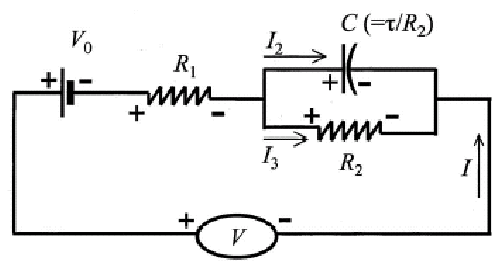
Dr. Ranade and Stan Atcitty worked with Mr. Duff of PCCAP, Inc. on a demonstration of how biased electrolytic (Polarized or 'dc') capacitors can be connected back-to-back to create ac capacitors. The benefit is a substantial weight and footprint reduction in ac application. A test protocol was evolved and tests will be conducted.

Dr. Ranade is also continuing his study of different conventional electro-chemical, and hybrid capacitor technologies with respect to energy storage applications in power systems. This study will be presented as a formal report.

↑ Table of Contents

VRLA Battery Life Study

The goal of this study is to develop a model of VRLA battery life for use in float applications. The model could be used to predict battery failures so that maintenance and replacements could be furnished in a timely manner. The intent is to be able to anticipate cell failures far enough in advance to install replacements before battery down time is actually incurred.



Equivalent circuit model currently used in this modeling effort.

Valve-regulated lead-acid (VRLA) battery life prediction continues to be problematical and its failure modes are not well understood, particularly by the user community. The inability to predict battery failures has led to a situation in back-up power applications where costly inspections and performance monitoring must be performed frequently to verify system readiness in case a utility power outage occurs. This situation is especially troublesome given that one of the expected benefits of a VRLA battery system is reduced maintenance cost.

In this study, appropriate, measurable battery characteristics are selected and related to float life through advanced mathematical modeling. In addition, fuzzy logic techniques are applied to determine the relationship of battery use profiles, battery characteristics, and battery failure mode patterns to float life.

The general approach is to first survey existing battery life data and augment it with additional test data as needed. Inductive models, such as artificial neural networks (ANNs), will then be constructed using the battery properties that are most strongly correlated with float life. The models will be adaptive and can, therefore, be easily refined as more data become available or as additional field experience is accumulated.

Initial work focused on developing a practical capability to model VRLA battery performance and degradation. A review of recent literature has shown that an equivalent-circuit, diagram-based approach may be promising; although it would need to be extended to include other important aspects of battery behavior. For battery float life prediction, these aspects would include self-discharge, charging efficiency, transport properties, and degradation processes.

Second Quarter Status

Battery Performance Simulation Model — Equivalent-Circuit (EC)-Based Approach

During this quarter, efforts focused on developing a more robust model for performance and life prediction based on the equivalent circuit model shown in the figure above, or a variation of it.

One possibility is to utilize data available from the lithium-ion batteries tested under the DOE Advanced Technology Development (ATD) program. The SNL test group has provided the most recent set of test data, which includes capacity fade and impedance change data associated with SOC and temperature during calendar thermal aging.

We were interested in using this particular set of data, since it is the only set available that has various aging conditions to allow us to assess the temperature and SOC dependence. The data also contains impedance changes through the various aging conditions; thus it is useful to analyze the changes in the circuitry elements as a function of aging.

We also received assistance from Angel Urbina of the Validation and Uncertainty Quantification Department at Sandia to allow us use of the data abstraction tool for impedance data visualization and for making the data available for impedance analysis.

Fuzzy-Inference System and Modeling

When Task 1 begins, to provide reliable data for life prediction, we will resume the development of the failure mode pattern recognition using the fuzzy logic techniques. This is the benefit of using such a set of data to provide estimates of the temperature and SOC dependence of the cell life performance.

Integration with Neural Network Modeling Efforts

Angel Urbina and his co-workers in ACTA have begun to use the EC model to generate thermal and rate dependent data for ANN training. A quarterly report was released recently that shows some success in the ANN model development.

Ideally, neural network models should be developed with measured quantities that relate to battery life. The first phase of this project trains neural network models using the capacity degradation cycle histories generated from an equivalent circuit model developed by Dr. Liaw. For training, cycle histories were generated over six temperatures, ranging from 10ºC to 60ºC, with an interval of 10ºC; and six discharge rates (C/N) with N ranging from 3.0 to 1.0, with an interval of 0.4.

Two neural network models were developed based on back propagation (BP) training and connectionist normalized linear spline (CNLS) with a radial basis function. The CNLS neural network was trained using five linear splines. The BP neural network was a three-layer perception with four neurons in the middle (hidden) layer, and trained with the Levenberg-Marquardt nonlinear least squares algorithm.

After training, the ANN models were evaluated at cycle histories generated over 12 temperatures, ranging from 10ºC to 65ºC with interval of 5ºC, and eight discharge rates, with N ranging from 1.5 to 3.25 with an interval of 0.25. This included all exemplars used in training. Both of the CNLS and BP models show reasonably good fit at the training points, and larger error at off-training points. Both models tend to exhibit larger errors at high discharge rates where there is a discontinuity when charge capacity falls to zero. A limited amount of extrapolation both for temperature and discharge rate was done.

Work Planned

In addition to CNLS and BP, other neural network models will be explored. An adaptive recurrent neural network scheme is a future goal of this project, since it is more suited to handle the variations in operating environment and battery intrinsic properties.

We will continue the modeling on the ATD Li-ion cell data by analyzing the impedance data to generate accurate parameters for the EC model and predict cell performance with validation from the test data.

We intend to provide the ATD Li-ion data and model to the ANN team to help them train the ANN model and develop necessary techniques.

Finally, we will refine both the EC and ANN models using any available VRLA battery data and conduct tests to validate where gaps exist and we will deploy the fuzzy logic techniques for failure mode pattern recognition.

↑ Table of Contents

Short vs. Long-Term Energy Storage Technologies Assessment

This assessment is a continuation of the study performed in FY99 that identified technology opportunities for both short and long duration applications of energy storage.

Based on the first study, the comparison of storage technologies with alternative options on a life cycle cost basis was identified as needing further analysis. While first-cost considerations will commonly favor generation, life-cycle costs (including the impacts of environmental effects) might favor storage.

These issues will be investigated to quantify the tradeoffs and comparisons using internal combustion generators fueled by a variety of sources, including natural gas, hydrogen, and diesel. In addition, more detailed analysis of the various technologies for the utility applications of storage defined in the *Opportunities Analysis Phase 2* study will be performed. Characteristics to be evaluated include energy density, power density, and duration of charge and discharge.

Second Quarter Status

In the second quarter, a draft SOW was written for continued analysis. Early next quarter this SOW will be placed for continuing the project.

The Phase 2 report titled "*Long vs. Short-Term Energy Storage Technologies Analysis, A Life-Cycle Cost Study*" is in final mark-up and will be published in May 2003.

↑ Table of Contents

ESS Web Site

The public access web site is currently being redesigned to improve the availability of information on Energy Storage Systems to the public. It will operate through an external server at Sandia National Laboratories.

↑ Table of Contents

California Energy Commission/DOE Energy Storage Initiative

During FY02, the California Energy Commission (CEC) and the DOE formulated a plan for an energy storage initiative that would consist of up to six demonstrations of energy storage applications, to be sited in California. Funding of $5M is being provided by the CEC. The CEC will provide all administrative support for the project; while DOE/Sandia will provide all technical support.

The initial CEC/DOE Energy Storage Initiative Workshop was held at the Public Utility Commission in San Francisco, California on September 4, 2002. Approximately 20, personally-invited utility industry representatives and customers attended to discuss the overall demonstration program and to help set the ground rules for the forthcoming Request for Proposal

(RFP). The workshop brought a small group of California stakeholders into a meeting to discuss the potential opportunities in California.

Other meetings are scheduled, which will lead to the release of an RFP by the CEC in late Spring 2003 It is anticipated that the first contracts will be placed by the CEC in the first quarter of FY04.

Each demonstration will operate under CEC/DOE/SNL monitoring for up to three years after contract award.

Second Quarter Status

A Contract Opportunity Notice (CON) was issued by the CEC in January, which announced the CEC/DOE Energy Storage Initiative Program to the general public. In conjunction with the release of the CON, all interested persons were invited to attend a public workshop at the CEC in Sacramento, CA in mid-February 2003.

More than 100 attendees from the energy storage industry were present at the one-day workshop. Many questions were asked and issues were discussed in a very animated meeting. Responses to these questions and related information can be found at the CEC website: www.energy.ca.gov/pier/EnergyStorageBB/phpBB2/.

The Request for Proposal (RFP) is planned for release in early June 2003.

↑ Table of Contents

Economic Evaluation Support for CEC/DOE Energy Storage Initiative

Baseline economic metrics are needed for evaluating responses in support of the CEC/DOE Energy Storage Initiative RFP development activity (See above***: California Energy Commission (CEC)/DOE Energy Storage Initiative***). The metrics are to be developed in the form of a handbook prepared by an expert in the economics of energy storage systems.

Because of their expertise in the economics of utility and energy storage applications, DUA was selected to produce the handbook. The handbook will be written for general use throughout the United States and will contain an appendix specific to the economics of California. In addition, it will allow bidders for the CEC/DOE Energy Storage Initiative to develop their economic analyses using a standard evaluation system.

Under the contract, DUA will also provide expert economic consulting support and assist the CEC/DOE team in evaluating the economic benefits of projects proposed for the CEC/DOE Initiative.

Second Quarter Status

The initial draft of the handbook was delivered in late February. Priority for the California appendix has been established in order for the California Handbook to be ready for distribution with the CEC RFP in early June 2003.

↑ Table of Contents

United States Coast Guard, National Distress System, Electric Power System Optimization Study

This is a new project that originated during the current quarter of FY03. It is a Sandia National Laboratories (Sandia), Work For Others (WFO) "funds-in" program that is being cost-shared by the ESS Program. This is the first Department of Homeland Security WFO project managed by Sandia.

For the past several years, Sandia has worked closely with the US Coast Guard in assisting that organization to improve battery systems management in the electric power systems currently in use at remote sites in the National Distress System (NDS). Recent developments at Sandia in the optimization of system management techniques for parallel battery strings have the potential to significantly improve battery performance and life expectancy for batteries used in the NDS power systems.

In order to evaluate the expected increase in performance of the NDS power system, a study has been proposed that will be conducted at the Sandia National Laboratories Distributed Energy Test Laboratory (DETL). This study will compare the performance results of two identical NDS power systems, one operated in its original configuration and the second operated under the control of an advanced battery management system that has been developed by Sandia National Laboratories.

Status

The WFO was approved on 3/24/03. Work on this project is expected to begin in a mid-May 2003 timeframe. The DOE/ESS Program cost share portion of this project will include project management and operational analysis of the systems under test at Sandia's DETL.

END OF REPORT

↑ Table of Contents